Frequency and System damping assistance from HVDC and FACTS controllers

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***Abstract*--HVDC transmission systems have led the way in providing assistance to power system stability from a source other than a generator. Since 1972 when the Nelson River transmission entered service in Canada, the DC system controls have been used to modulate the DC power to help stabilize the power frequency at either end of the link and to dampen power oscillations between weakly connected areas of the AC system.**

The principles developed at Nelson River have not only continued to give good service, but also have been applied elsewhere. In India, DC connections between separate electrical areas have been built to encourage energy trading. The systems they interconnect are relatively weak. An example DC back-to-back project illustrates how suitable DC power controls can assist both frequency stabilization and damping of power oscillations within the AC systems.

FACTS controllers can assist too. The Static Var Compensator (SVC), though leveraging only reactive and not real power, can increase the power transfer capability of an AC system by stabilizing the voltage. It is also possible to vary the voltage control setting to provide additional damping.

Index Terms - FACTS, HVDC, Interconnections, Power Modulation, Power System Stability.

I. HVDC

Direct Current transmission offers an asynchronous transfer of electric power. The transfer can be between independent systems or between points within a system. Though the treatment of these two cases will be different, the essential contributions that comes with a DC (but not an AC) link are:

- Power flow can be controlled precisely and very rapidly, in either direction, not only to wheel energy but also to help the control of either or both AC systems. By controlling its power transfer, the DC can help the system operator to dictate the power flows in the adjacent ac lines.
- By rapidly changing its power transfer, it can improve ac system stability. It can modulate its throughput power to damp out post-disturbance swings.
- Unlike a synchronous connection, dc transmits no fault current and buffers one network from faults in the other. As long as there is an AC voltage, the DC terminal will operate.
- It can act as a voltage regulator by switching its reactive power banks or by adjusting control angles to absorb more or less reactive power. In this way it can exercise Mvar exchange within specified limits.

A. Canadian Example

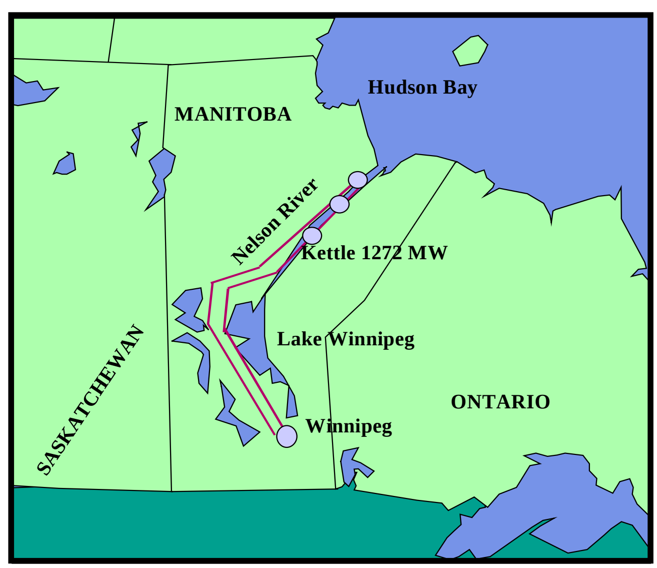

Fig. 1: The two bipoles of the Nelson River DC system.

To give an example, over 60% of the load of the Province of Manitoba in Canada is supplied by the Nelson River HVDC project which brings hydro-generated power 900 km to the load centre at Winnipeg. The project consists of two bipoles (Fig. 1). It supplies four ac systems (Fig. 2) which, though

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synchronous, tend to oscillate at a natural frequency of 0.5 to 1Hz. If the tie line to one of the four systems opens, a power imbalance will result. The HVDC controls respond to alter the DC power flow by the same amount as the tie line was previously carrying, so that the disturbance is cancelled out.

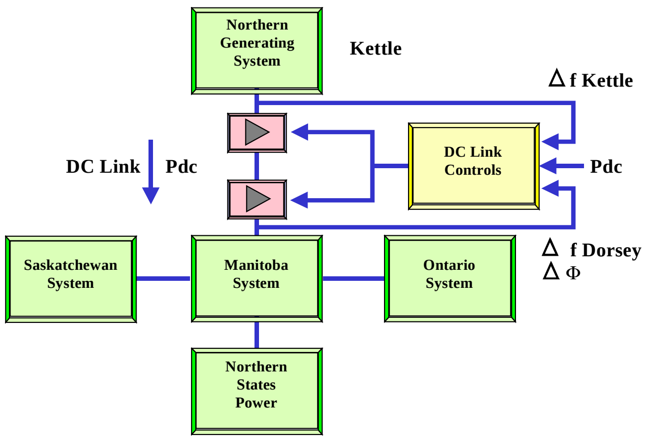

Fig. 2: Method of controlling AC system swings by DC power modulation

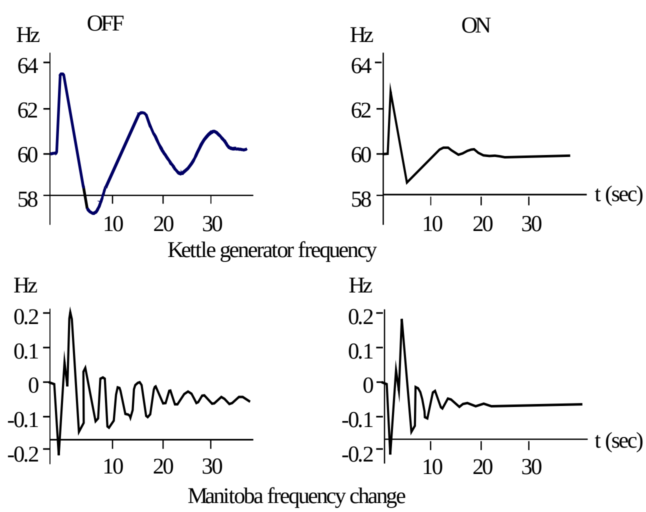

Fig. 3: The effect of DC power modulation

A further control of tie-line power oscillations is necessary. It responds to changes in the AC busbar voltage angle, a convenient measure of the change in tie-line flows within the critical frequency of oscillation, and alters DC power flow, bringing substantial damping improvement (Fig. 3) to the operation of the network. Alternatively the modulation of power is possible in response to the frequency of one or both systems [1].

A major benefit of HVDC transmission compared to AC is the inherent robustness of the interconnection in the face of difficult AC system conditions and its ability to isolate an AC system from the worst effects of a transient disturbance in an adjoining network. An HVDC link will continue to regulate power even under the conditions of varying ac voltage, frequency and phase angle. The ability of the HVDC to cope with the varied AC conditions can even permit the interconnection to be made with DC when it would be impossible with AC.

B. Indian Example

In India there are five separate regions, with a disparity of resource and demand and a wide variation of operating frequency and voltage on a day-to-day basis. To synchronize any two was difficult for two reasons: the need to maintain stability and the organization necessary to schedule power exchange. The needs of resource allocation have however demanded an ability to transfer power between them.

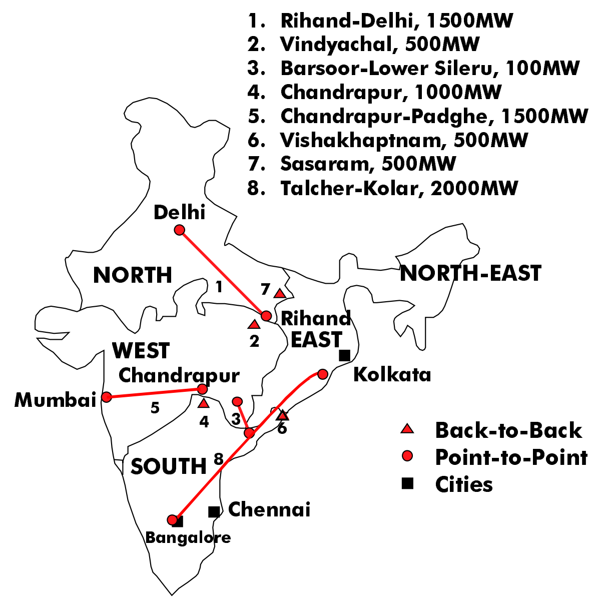

Fig. 4: The electrical power regions of India

System studies were carried out to evaluate the viability of interconnecting two Indian regions using AC and DC. Each is geographically large and with a substantial demand of approximately 19,000MW at peak times. Each of the regions is a relatively weak network even at 400 kV or 220 kV and consequently inter-regional synchronisation is not readily achieved.

The study primarily investigated the post-fault transient stability of two alternative types of interconnection (AC and HVDC) between the regions, namely:

- A double circuit, 400kV AC transmission line of nominal capacity 500 MW, assuming that matching of the two system frequencies and voltage levels is achievable
- A double circuit, 400 kV AC transmission line of nominal capacity 500 MW, with a 500 MW HVDC Back-to-Back link connected at one end.

Operation of the system was simulated under peak load flow conditions with transfer through the inter-regional tie. With the regions interconnected, three-phase faults of different intensities were applied at representative locations around the networks. The variations with time of generator rotor angles and terminal voltages were examined together with the power flows in the interconnection.

C. Results

Figs. 5, 6 and 7 show results of a three phase fault applied to one circuit of an ac transmission line in Region A. If there is no AC or DC interconnection, the system on its own can recover from this fault. In contrast, Fig. 5 shows that, when the regions are interconnected with an AC tie, the tie will be lost with continuously increasing oscillation of both terminal voltage and line power flow in Region A. The AC line power is measured in one of the circuits that supplies the link.

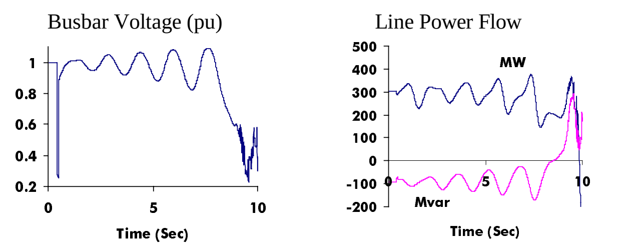

Fig. 5: Dynamic Response (Region A): Regions Connected by AC Line

However, the results for the same study with an HVDC back-to-back link in series with the AC interconnection can be seen, in Fig. 6, to be stable with the voltages and power flows returning to new stable values with decreasing oscillations.

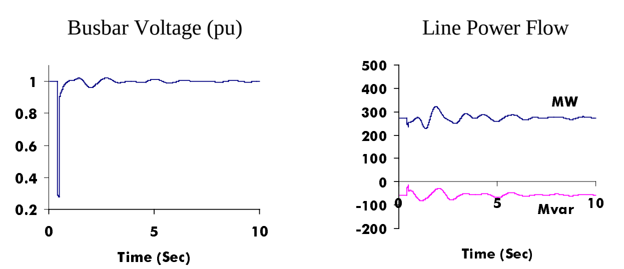

Fig. 6: Dynamic Response (Region A)

With the AC interconnection the effect of the faults was also transferred to Region B resulting in similar unstable oscillation in Region B as shown in Fig. 5. However, when the interconnection includes the Back-to Back DC link there is little disturbance in Region B as shown in Fig. 7. The DC link has buffered the disturbance in Region A from Region B and ensured stability of the whole system.

These study results match the performance of the real systems in which it has been found that even when conditions have permitted the interconnection using an AC tie, the system will become unstable, but with the HVDC tie, operation is satisfactory [2].

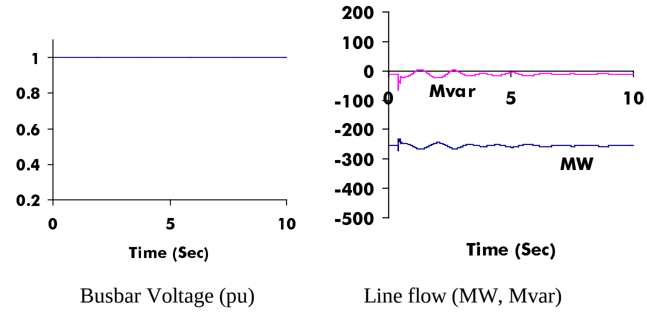

Fig. 7: Dynamic Response (Region B): Regions Connected by DC

II. ADDITIONAL CONTROL BENEFITS OF HVDC

Power flows can be controlled through an HVDC link in response to control inputs and these can be programmed to act for the overall benefit of the AC system or systems. In addition to power oscillation damping or power modulation already described, it is possible to apply rapid changes in the level of power transfer in response to changed system conditions. Such applications are specific to the system conditions and must be evaluated for each case. One strategy that has been successfully applied is to reduce the power through the DC link in response to dropping AC voltage in the supplying system. The principle is to relieve a system under stress by reducing some of its load, a strategy less disruptive than load shedding, since no customer is interrupted. There will however be a reduction of power supplied to the receiving system, which must then draw on its reserves during the disturbance.

Finally the power exchange can be adjusted over a slightly longer time scale to provide Frequency Control, provided that the change in power flow that will assist one system can readily be supplied by the other.

Dynamic overvoltages can arise on one side of a DC link when power flow is interrupted by a voltage collapse on the other side. An HVDC link can be utilised to control voltage through its inherently variable power factor. The valve firing process is maintained in effect developing a DC by-pass on the faulted side, the current through the by-pass being controlled to regulate the voltage on the healthy side.

As a regular feature, steady state assistance can be provided to either system because there is reactive power available at the convertor. By advancing the firing angle the Convertor will absorb more reactive, after which filter switching may be appropriate.

III. ASSISTANCE FROM FACTS CONTROLLERS

Power system textbooks show that the power carrying capacity of a power line is a function of the two end voltages, the voltage angle difference and the reactance between the two ends. If therefore, at a point on the route, the voltage can be supported on a continuous basis, the capacity limit applies to the sections between support points rather than to the whole length. This is the principle behind the application of Static Var Compensators and STATCOM to AC power transmission [3]. In effect, power electronics can stretch the capacity of a system by shoring up the voltage at the intermediate points, providing a means of extending the safe loading of a large network where the existing lines have some unused thermal capacity. More recently a need to react quickly to changing power flow patterns in response to free market forces has dawned. Relocatable static Var compensators have already been installed and one has been relocated in England as a response to this situation. The STATCOM gives a faster and greater response to the same requirement [4].

It is possible to obtain a further benefit by adjusting the voltage signal applied to the controls of a SVC, in response to some system parameter such as line flow or voltage angle. Care is needed to ensure that this process does not degrade the voltage elsewhere on the system especially in a well integrated system with many voltage levels [5].

Strengthening interconnections within an AC system creates a mesh or grid. Sometimes distant parallel lines pick up an unexpected share of the power intended for any new line, causing overloads or capacity restrictions, due to sag of voltage. Line outages will exacerbate this effect. This "loop-flow" phenomenon can be corrected by adjustment of phase-angle or by the controlled injection of a series voltage. Mechanical phase-shift transformers can adjust phase-angle or there are electronic equivalents: injection of a series voltage is possible by the Static Synchronous Series Compensator (SSSC) or the United Power Flow Controller (UPFC) with a power-electronic response of about one cycle. This is a more rapid but not necessarily a more economic solution.

IV. CONCLUSIONS

Power electronics have proved a powerful force in contributing to power system stability. Damping signals can modulate the power transferred by a HVDC link to stabilize oscillations where methods based on generators cannot reach.

By avoiding the synchronization of two systems, a DC link transfers power but offers a barrier to the transfer of faults. The paper has demonstrated that instability occurring when two regional systems are synchronized can be solved by the insertion of a back-to-back DC link. A substantial array of control options becomes available when such a link is introduced. Both the power passed through can be adjusted to relieve a system under stress and the reactive power can be made sensitive to the system's transient requirements of voltage control.

Static Var compensators (and STATCOM) provide AC power systems with support at intermediate network points, extending a system's safe power transfer capacity.

V. REFERENCES

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